(12)

TECHNICAL
MEMORANDUM
NCSC TM271-79

NOVEMBER 1979

DATA ANALYSIS FOR OCEAN THERMAL ENERGY CONVERSION (OTEC)

SUSAN M. TUOVILA

NAVAL COASTAL SYSTEMS CENTER
NCSC
PANAMA CITY, FLORIDA 32407

Approved for public release;
distribution unlimited

NAVAL COASTAL SYSTEMS CENTER

PANAMA CITY, FLORIDA 32407

CAPT RAYMOND D. BENNETT, USN
Commanding Officer

GERALD G. GOULD
Technical Director

ADMINISTRATIVE INFORMATION

The Heat Exchanger Heating task was sponsored by the Department of Energy under Interagency Agreement ET-78-I-01-3218, Task Number 13218, Work Unit Number 01.

The author wishes to thank Mr. David Boswell of DTNSRDC, Annapolis, Maryland for his work on OTEC software development. The assistance of Mr. Glenn Grannemann of Carnegie-Mellon University, Pittsburgh, Pennsylvania, in reviewing Panama City OTEC data analysis techniques is acknowledged.

Released by
W. H. Tolbert, Head
Environmental Sciences Division
November 1979

Under Authority of
M. J. Wynn, Head
Coastal Technology Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NCSC-TM-271-79
2. GOVT ACCESSION NO:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): DATA ANALYSIS FOR OCEAN THERMAL ENERGY CONVERSION (OTEC)
5. TYPE OF REPORT & PERIOD COVERED: Technical Memorandum
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Susan M. Tuovila
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Coastal Systems Center, Panama City, Florida 32401
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Task No. 13218, Work Unit No. 01.
11. CONTROLLING OFFICE NAME AND ADDRESS:
12. REPORT DATE: November 1979
13. NUMBER OF PAGES: 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Thermal energy conversion
Data analyses
Computer control system

Identifiers:
OTEC (Ocean thermal energy conversion)
Ocean thermal energy conversion

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes computer control and analysis techniques for the Ocean Thermal Energy Conversion (OTEC) system at the Naval Coastal Systems Center (NCSC) in Panama City, Florida.

Test site characterization, cleaning systems, and the physical structure of the OTEC system are discussed briefly. Data sampling and analysis techniques are then explained in detail. A discussion of heat transfer theory and copies of software analysis routines are also included.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

	Page No.
INTRODUCTION	1
TEST SITE CONFIGURATION	2
CLEANING SYSTEMS	2
COMPUTER CONTROL SYSTEM	3
DATA SAMPLING	4
DATA ANALYSIS	6
SYSTEM RELIABILITY	18
APPENDIX A - ANALYSIS PROGRAM LISTOUTS	A-1

LIST OF ILLUSTRATIONS

Figure No.		Page No.
1	OTEC Data Sampling and Analysis	5
2	Wilson Plot	7
3	Cooling Curve Plot	9
4	Typical Analysis Parameters Printout	15
5	Mean Daily Fouling Resistance Values	17

LIST OF TABLES

Table No.		Page No.
1	Description of Tube Parameters	11
2	Values of Tube Parameters	12
3	Analysis Parameters	14
4	Tube Data Listout	16
5	Parameter Errors	19

INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) is the concept for a system which will extract energy from the ocean by taking advantage of the sizable temperature difference between surface and bottom water in a tropical ocean[1]. A fundamental part of an OTEC system is a large section of heat exchangers through which the energy transfer is made. It is crucial to keep the surface of these heat exchangers clean because fouling by organisms in sea water can cause deterioration of the heat transfer effectiveness. The Naval Coastal Systems Center (NCSC) investigated cleaning techniques that would effectively prevent fouling in metal tubes over a long period of time.

The physical structure and cleaning systems of the OTEC assembly at Panama City, Florida have been described in several papers[2][3][4] and will be dealt with only briefly here. This report will describe the computer driven control and data analysis system used in conjunction with the mechanical system. This will include explanations of the physical computer setup and its interaction with hardware components of the system, the software methods of sampling and data management, and data analysis techniques. A brief discussion of the underlying theory of heat transfer is also included.

---

[1] Griffin, O. M., *OTEC, Power from Thermal Gradients,* Sea Technology, pp. 11-15, August 1977.

[2] Fritsch, A., Adamson, W., and Castelli, V., *An Evaluation of Mechanical Cleaning Methods for Removal of Soft Fouling from Heat Exchanger Tubes in OTEC Power Plants,* Proceedings of the Ocean Thermal Energy Conversion (OTEC) Biofouling and Corrosion Symposium, Seattle, Washington, 1978.

[3] Braswell, J. A., Lott, D. F., and Hedlicka, S. M., *Preliminary Evaluation of Flow-Driven Brushes for Removal of Soft Biofouling from Heat Exchanger Tubes in OTEC Power Plants,* Ocean Thermal Energy Conversion (OTEC) Workshop, Washington, D. C., January 1979.

[4] Lott, D. F., and Tuovila, S. M., *Biofouling Countermeasures - Status of Two Mechanical Systems Systems and Chlorination,* Sixth Ocean Thermal Energy Conversion (OTEC) Symposium, Washington, D. C., June 1979.

TEST SITE CONFIGURATION

The test site at NCSC is located on the shores of St. Andrew Bay, an estuary of the Gulf of Mexico, at Panama City, Florida. The OTEC piping assembly and computer system was located on a pier, with the seawater being pumped to test sections from a depth of approximately 7 feet[3]. Three self-priming centrifugal pumps were available with one or two being used to pump seawater from the bay into a header. Twelve tubes were fed from the header; six were of titanium and six of 5052 aluminum so that the cleaning systems could be tested on two different metals. Water flowed from each tube back into the bay, with the flowrate manually adjusted with a valve at the outlet.

CLEANING SYSTEMS

The tubing system contained four control tubes, two tubes in a flow-driven brush cleaning system, two tubes in a reciprocating sponge ball cleaning system, and four tubes in a chlorination system. All cleaning systems worked automatically and were controlled by timers.

One pair of control tubes (one aluminum and one titanium) were allowed to foul freely to provide data on the amount and kind of fouling present. The other pair of control tubes were cleaned daily and served as an internal check of the data gathering system.

The flow-driven brush cleaning system consisted of one aluminum and one titanium tube through which a nylon brush was passed. At each end of the tube was a nylon basket in which the brush was trapped. Periodically, water flow in the tube was reversed to force the brush to the other end of the tube. The brush diameter was slightly larger than the tube's inner diameter and would shear the fouling material off the tube walls.

The recirculating sponge ball cleaning system consisted of one aluminum and one titanium tube in which a sponge ball of a slightly larger diameter than the tube was circulated. The ball was held in a valve and released periodically when the valve was turned. When the ball had gone past an optical sensor, the valve was turned back to its original position and the ball was diverted into a catcher which placed it back into the circulating system.

---

[3] ibid.

The control, brush, and sponge ball systems have been described by Lott and Tuovila[4]. Tests with the chlorination system have not yet begun. This system consists of two aluminum tubes and two titanium tubes. A chlorine generator releases a known concentration of chlorine into the system; chlorine release may be pulsed at regular intervals or may be continuous so that the concentration of chlorine within the tubes remains constant.

COMPUTER CONTROL SYSTEM

A DEC PDP-11/34 computer was used to provide system control and data analysis. Ideally, this system should run continuously without much operator assistance. The main areas of computer control are pump selection, tube selection, and heater control; if necessary, the entire test could be halted by the computer.

Pump performance was monitored throughout a test. If a pump failed to provide uniform flow, an error message was printed to alert the operator to a problem. If the bad pump performance continued, the computer was programmed to automatically shut down the malfunctioning pump and simultaneously activate another pump through a relay panel.

Heaters in the OTEC system consisted of copper heater cylinders which were press fitted to the outside of the heat exchanger tubes. Voltage to the heaters was controlled by a Variac panel, which must be set manually and read into the computer via a DEC AD11-K analog to digital converter. The computer was programmed to be responsible for turning individual heaters on and off, monitoring rates of heat up and cool down of sea water in the tubes, and setting heater voltage limits. The timing schedule for heat up and cool down, and the allowable voltage limits were pre-set by the computer but these default conditions could be altered by the operator at the beginning of a test. Once a test had begun, the computer would continuously turn the heaters on and off according to the prescribed cycle, monitor heater performance, and periodically sample and print voltages. If a heater built up more voltage than a prescribed upper limit, that heater was turned off by the computer and the corresponding tube was "dropped" from the test. This was to prevent damage to heat transfer units.

---

[4] ibid.

Sonic flow meters were used to measure flow velocity and read into the computer via the A to D converter. Flow had to be set manually via a PVC valve at the output of each tube, but the computer monitors flow rate throughout a test. Maintaining a constant water flow was crucial to correctly determining the heat transfer characteristics of a tube, so any sudden change in flow would trigger an error message to alert the operator. Intermittent or sluggish water flow would cause the heaters to heat the tube excessively or erratically, and that tube would be dropped from the test.

DATA SAMPLING

Software sampling programs, in FORTRAN IV and MACRO assembly language, were initially planned and written by personnel at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) at Annapolis, Maryland. These routines allowed the computer to read signal output by hardware components of the OTEC systems. An analysis cycle consisted of two parts: (1) heat up, when the heaters are on, and (2) cool down after the heaters have been shut off. Samples were taken during the cool down cycle to determine the exponential heat decay curve for each tube.

The general data analysis scheme is outlined in Figure 1. Four quantities were sampled for each tube: (1) time, (2) heater voltage, (3) water temperature in degrees Celsius, and (4) flow rate in feet per second. Aluminum tubes were sampled successively with heater voltage and water temperature sampled every 3 seconds, and flow rate measured every 9 seconds. For titanium tubes, the sampling rates were twice those for aluminum tubes because the cooling curve for a titanium tube has a longer time constant than that of an aluminum tube. For clean tubes, a time constant of 50-55 seconds is typical of the cooling curve for a titanium tube and 30-35 seconds for aluminum. Sampled values were displayed on a CRT, which was updated every 3 seconds, and printed on a teletype every 10 minutes. Time was provided continuously by a battery driven quartz clock inside the computer and provided for automatic restarting of an OTEC test following any interruption of power to the computer. Sampled values were stored in an array for the duration of sampling cool down time and were printed on a teletype during the next heat up cycle; and were used to provide an analysis of that tube. Heat up time was set at 18 minutes with a cool down time of 12 minutes yielding 48 analyses per tube each day.

(Text Continued on Page 6)

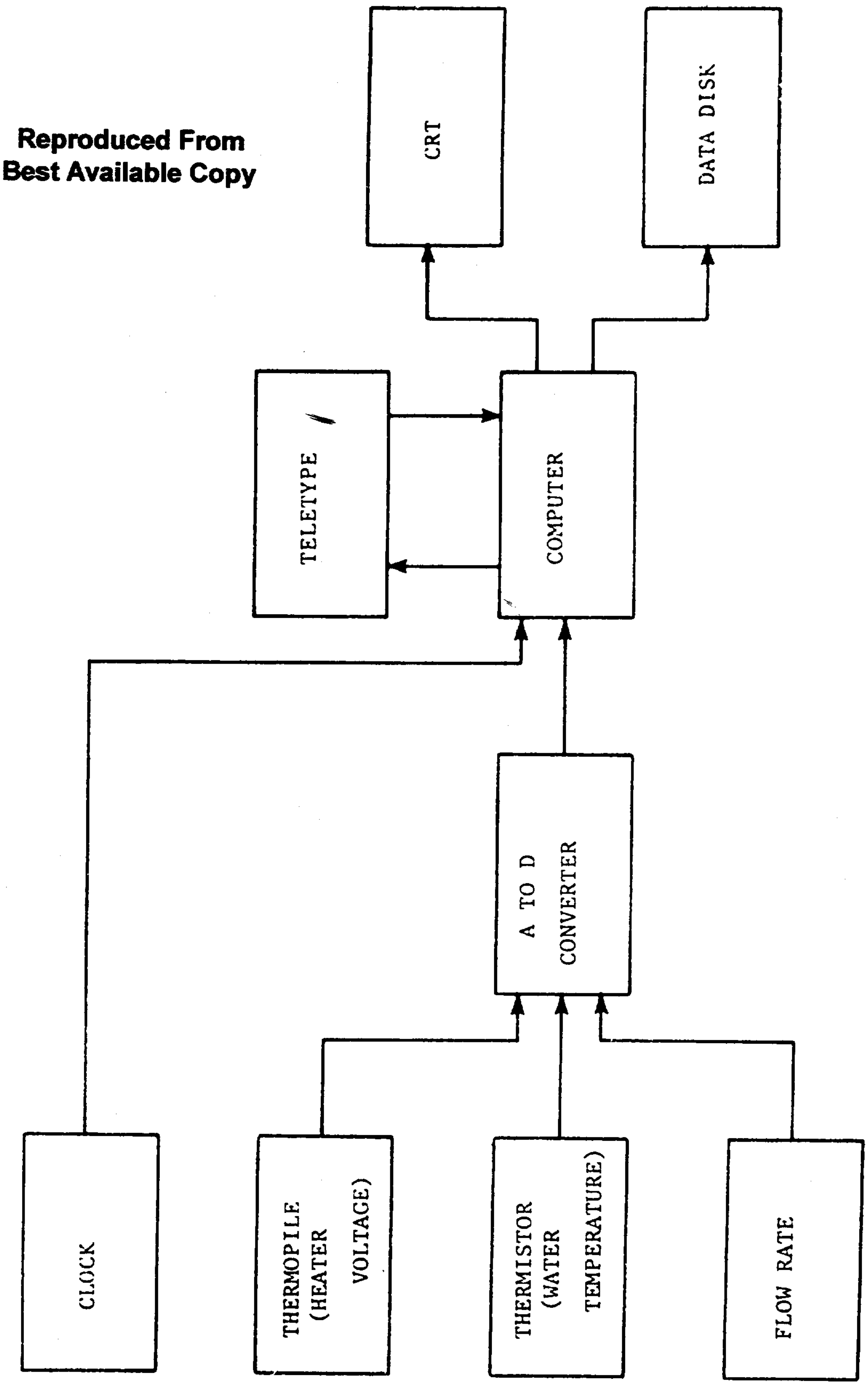

FIGURE 1. OTEC DATA SAMPLING AND ANALYSIS

DATA ANALYSIS

Data analysis techniques were based on those developed at Carnegie-Mellon University[5] and were intended to determine changes in the fouling resistance based on the transfer of heat from the tube walls to the sea water flowing inside.

In determining the heat transfer coefficient in a tube, it was assumed that all resistance in the system was due to buildup of a fouling layer at the interface of the pipe interior and the flowing sea water. The resistance at other sites within the unit, such as that present in the copper block and at the interface between pipe and copper block, were assumed to contribute only negligibly to the total resistance in the system.

As a test progressed, the amount of fouling present was estimated from the changes in resistance from a baseline value determined from a Wilson Plot[6] done on data taken from each tube when it was clean. This plot is essentially a linear regression relating the inverse of flow velocity ($1/V^{0.8}$) with fouling resistance ($1/h$), where h is a measure of heat transfer. A sample Wilson Plot is shown in Figure 2. Slope was determined experimentally to be approximately 3.44×10^{-3} and the intercept at $1/V^{0.8} = 0$ should ideally be zero. The intercept normally takes a small positive value (approximately 1.0×10^{-4}) which represents the total amount of resistance in the system which is not due to biological fouling (assuming the tube has been properly cleaned). As fouling increases, the Wilson line slope should remain unchanged while the intercept increases, providing an estimate of how much the fouling resistance has increased over the baseline value.

During a test, sea water flowing through tubes in the heat transfer units was heated until the temperature of the tube walls stabilized at a temperature slightly above that of the water flowing inside. Then the heaters were turned off and the tubes cooled by the colder sea water flowing through them. assuming a constant flow velocity, the voltage decay of the cooling curve can be defined by the relation:

$$V(t) = V_o e^{-t/\tau} \tag{1}$$

---

[5]Fetkovitch, J. G., Fette, C. W., Findley, R. W., Grannemann, G. R., Mahalingham, L. M., Meier, D. L., and Runco, P. D., *A System for Measuring the Effect of Fouling on Heat Transfer Under Simulated OTEC Conditions,* Report COO-4041-10, Carnegie-Mellon University, December 1976.

[6]Wilson, E. E., *A Basis for Rational Design of Heat Transfer Apparatus,* American Society of Mechanical Engineers Transactions, Vol. 37, ASME Paper #1477, 1915.

(Text Continued on Page 8)

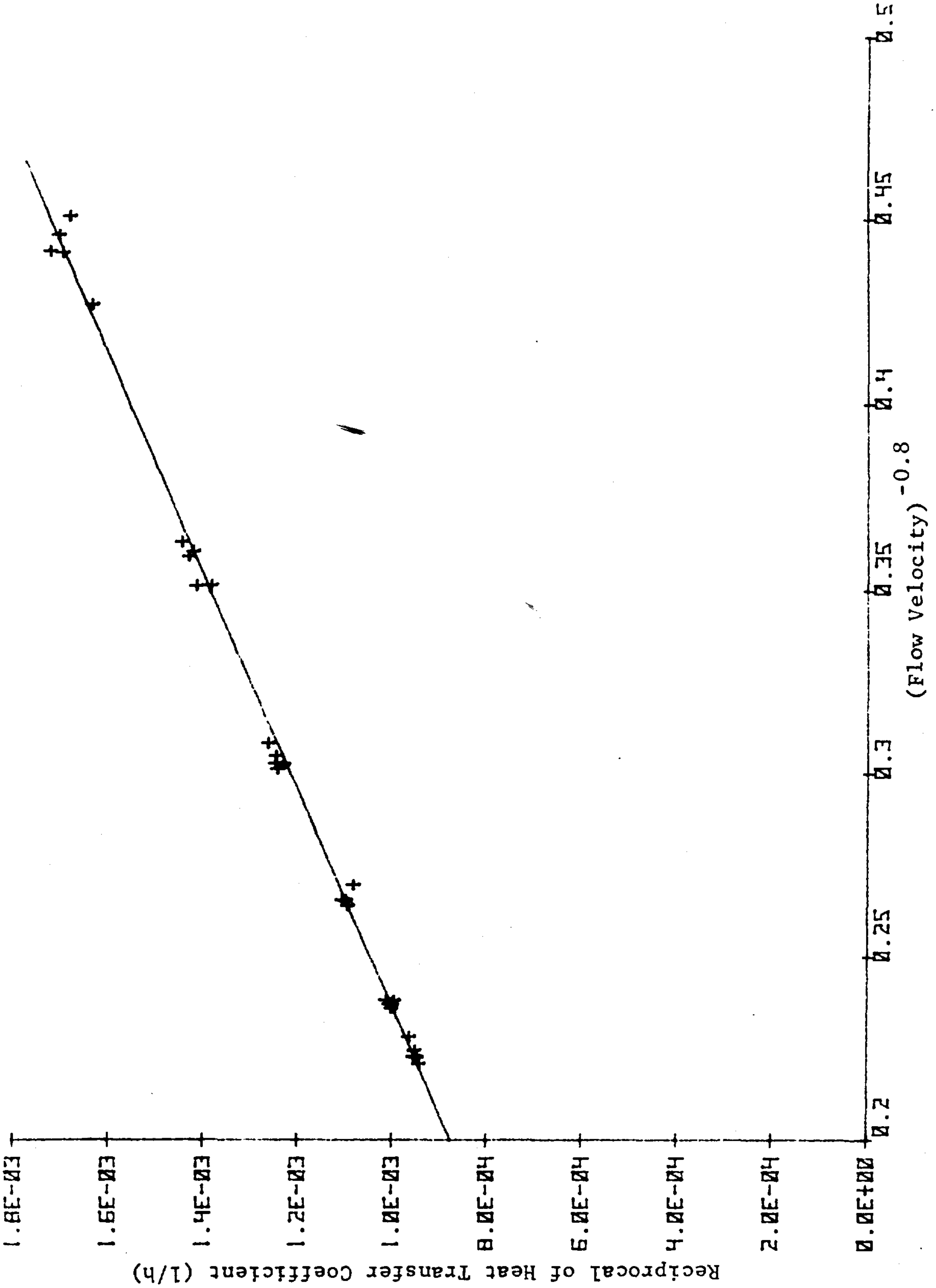

FIGURE 2. WILSON PLOT

where t is time; V_o is the steady state voltage achieved after a tube has been heated; τ is the time constant of the cooling curve; and V(t) is the voltage at time t. A plot of an exponential decay curve is shown in Figure 3. As fouling increases in a tube, the above relation will continue to hold, with increasingly larger values of τ.

In actual practice, the raw cooling curve data are modified before a time constant is determined. The first few seconds of the curve are discarded to ensure that the heater was turned off before data were taken. The actual time was deduced from experience with the physical system and set at 15 seconds for aluminum tubes and 30 seconds for titanium tubes for our system. Secondly, the cooling curve was normalized to zero by subtracting the minimum voltage achieved by the heater; this minimum was estimated by averaging the values of the last several voltages at the end of the cooling curve where the voltage had stabilized to a constant value. Finally, the curve was weighted to minimize bias caused by equipment noise, flow irregularities, and other random system perturbations.

The value of this background noise bias was assumed to be constant and was estimated by the standard deviation in the points used to determine the minimum heater voltage. Since low voltage values in this cooling curve will be affected by the bias more than greater voltage values, the weighting function, based on the determined system bias, weights higher voltages more than lower ones, using the relation:

$$w(t) = \frac{(V_n(t))^2}{s} \qquad (2)$$

where t is the time, $V_n(t)$ is the normalized voltage at time t, s is the standard deviation of the "zero" voltage, and w(t) is the weight applied to the voltage at time t.

Rather than performing an exponential regression on the cooling curve data, the logarithm, base e, of each data point was taken and a linear equation fit to the resulting line. Weighting of the curve was done in the linear regression routine LINFIT[7]. Taking the logarithm of both sides of Equation (1) yielded the relation:

$$\ln V(t) = \ln V_o - \frac{t}{\tau} \ .$$

---

[7] Bevington, P. R., *Data Reduction and Error Analysis for the Physical Sciences*, pp. 104-105, 1969.

(Text Continued on Page 10)

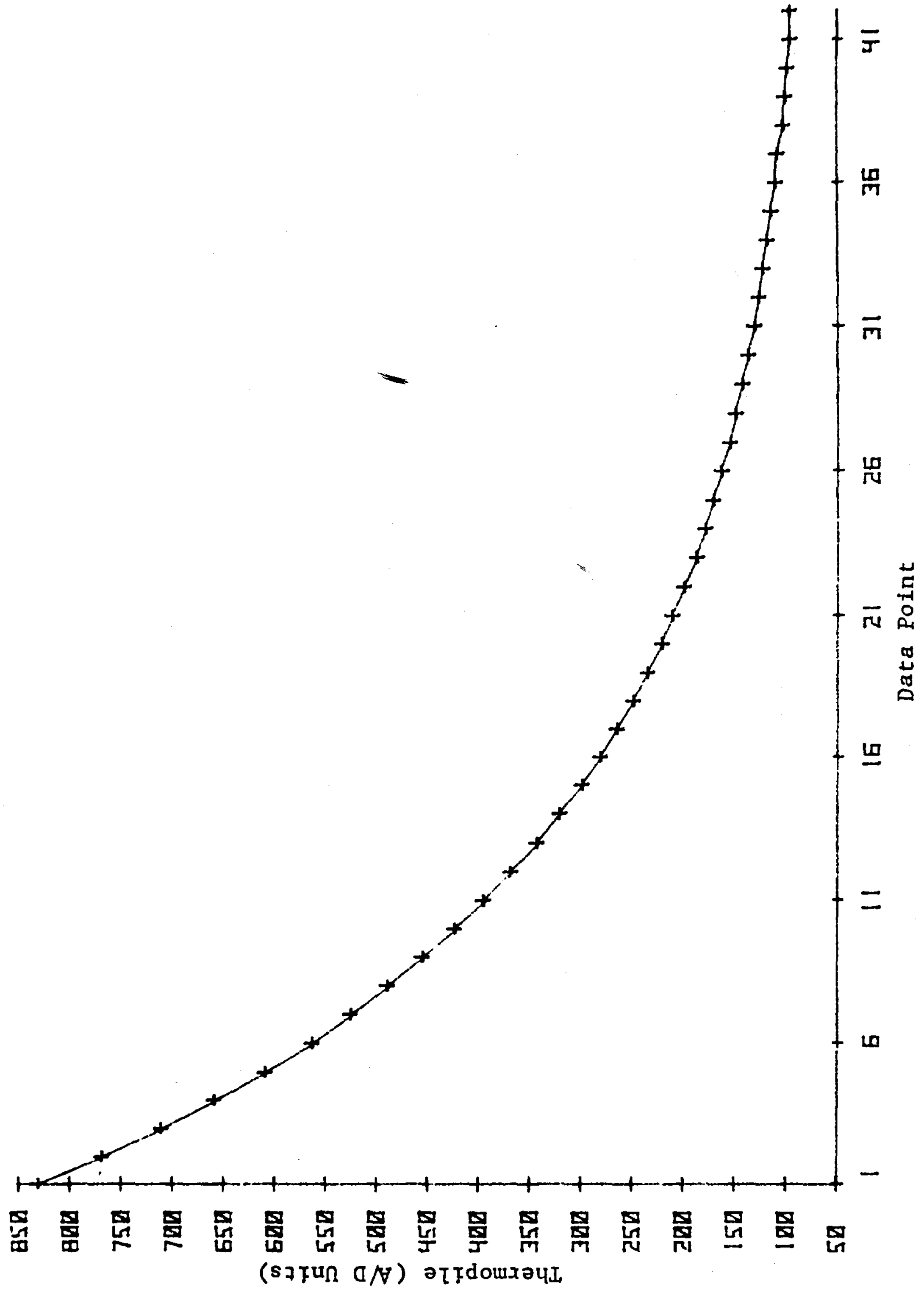

FIGURE 3. COOLING CURVE PLOT

Linear regression then determined the values of the unknowns V_o (starting or maximum voltage) and τ (time constant of the cooling curve). A correlation coefficient, R, and root mean square error, RMS, were also calculated for the linear fit.

Linear regression was performed twice for each cooling curve. The fit was done on the entire cooling curve (except for the points at the beginning which were previously deleted) and a preliminary estimate of the time constant (τ) determined. Then one time constant's worth of data from the beginning of the curve was fit and a final value of τ was determined. A more accurate fit was gained by not including the "tail" of the cooling curve where the voltage was approaching its constant minimum value.

Once the value of τ has been determined, the heat transfer coefficient can be calculated with the equation:

$$\ln h = A + B(\ln \tau) + C(\ln \tau)^2 + D(\ln \tau)^3 \tag{4}$$

where A, B, C, and D are constants based on physical characteristics of the tube (dimension, heat capacity, thermal conductivity, etc.). Table 1 gives a description of tube parameters with actual values for each tube being listed in Table 2.

This value of h had to be corrected because its calculation was based on the assumption that all the heat lost from the tube walls during cool down cycles was transferred to the water flowing through the tube. Two other sources of heat loss were considered: (1) into the air and (2) axial loss along the tube wall. Heat loss into the air was allowed for with the equation:[8][9][10]

---

[8] Sparrow, E. M., Hallman, and Siegel, T. M., *Turbulent Heat Transfer in the Thermal Entrance Region of a Pipe with Uniform Heat Flux,* Appl. Sci., Res., Section A., Vol. 7, 1955, pp. 37-52.

[9] Hartnett, J. P., *Experimental Determination of the Thermal Entrance Length for the Flow of Water and Oil in Circular Pipes,* Transactions of the ASME, Vol. 77, 1955, pp. 1211-1220.

[10] Allen, R. W., and Eckert, E. R. G., *Friction and Heat Transfer Measurements to Turbulent Pipe Flow of Water (Pr = 7 and 8) at Uniform Wall Heat Flux,* Trans. ASME, Journal of Heat Transfer, Vol. 86, Ser. C, No. 3, August 1964, pp. 301-310.

(Text Continued on Page 13)

TABLE 1

DESCRIPTION OF TUBE PARAMETERS

Parameter No.	Description
1	A: First constant for calculation of h
2	B: Second constant for calculation of h
3	C: Third constant for calculation of h
4	D: Fourth constant for calculation of h
5	RAD1: Inside radius of tube (in)
6	RAD2: 1/2 Machined O.D. of tube or copper heater I.D. (in)
7	RAD3: 1/2 O.D. of copper heater section (in)
8	AKCYL: Thermal conductivity of copper heater (B/hr ft ^{o}F)
9	AKTUB: Thermal conductivity of tube (B/hr ft ^{o}F)
10	HAIR: Air heat transfer coefficient for heat loss to air
11	HINTR: 1/h intercept on Wilson Plot (different for each tube)
12	ALENGTH: Length of heater section on tube (in)
13	TTHWLL: Wall thickness of thin tube section near heater (in)
14	VNOM: Nominal water velocity to which results are corrected (fps)
15	HRSLPE: Slope from Wilson Plot (different for each tube)
16	THINT: Thermistor calibration curve intercept (^{o}C)
17	THSLP: Thermistor calibration curve slope
18	FMINT: Flow meter calibration curve intercept (gpm)
19	FMSLP Flow meter calibration curve slope
20	IWNST: Points after cooling curve starts for data collection to start
21	IWN: Number of τ's for second data fit

1-19 are real numbers

20-21 are integers

TABLE 2
VALUES OF THE PARAMETERS

Parameter No.	Tube No. 1	2	3	4	5	6
1	13.577000	49.278000	13.577000	49.278000	13.577000	49.278000
2	-2.964000	-24.165001	-2.964000	-24.165001	-2.964000	-24.165001
3	0.401300	4.650300	0.401300	4.650300	0.401300	4.650300
4	-0.028200	-0.314180	-0.028200	-0.314180	-0.028200	-0.314180
5	0.524500	0.524500	0.524500	0.524500	0.524500	0.524500
6	0.640000	0.640000	0.640000	0.640000	0.640000	0.640000
7	1.500000	1.500000	1.500000	1.500000	1.500000	1.500000
8	225.899002	225.899002	225.899002	225.899002	225.899002	225.899002
9	79.830002	9.150000	79.830002	9.150000	79.830002	9.150000
10	1.570000	1.570000	1.570000	1.570000	1.570000	1.570000
11*	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	12.000000	12.000000	12.000000	12.000000	12.000000	12.000000
13	0.060000	0.115000	0.060000	0.115000	0.060000	0.115000
14	6.000000	6.000000	6.000000	6.000000	6.000000	6.000000
15*	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16	2.750000	2.750000	2.750000	2.750000	2.750000	2.750000
17	0.008789	0.008789	0.008789	0.008789	0.008789	0.008789
18	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
19	0.004883	0.004883	0.004883	0.004883	0.004883	0.004883
20	1	1	1	1	1	1
21	1	1	1	1	1	1

Parameter No.	Tube No. 7	8	9	10	11	12
1	13.577000	49.278000	13.577000	49.278000	13.577000	49.27800
2	-2.964000	-24.165001	-2.964000	-24.165001	-2.964000	-24.165001
3	0.401300	4.650300	0.401300	4.650300	0.401300	4.650300
4	-0.028200	-0.314180	-0.028200	-0.314180	-0.028200	-0.314180
5	0.524500	0.524500	0.524500	0.524500	0.524500	0.524500
6	0.640000	0.640000	0.640000	0.640000	0.640000	0.640000
7	1.500000	1.500000	1.500000	1.500000	1.500000	1.500000
8	225.899002	225.899002	225.899002	225.899002	225.899002	225.899002
9	79.830002	9.150000	79.830002	9.150000	79.830002	9.150000
10	1.570000	1.570000	1.570000	1.570000	1.570000	1.570000
11*	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
12	12.000000	12.000000	12.000000	12.000000	12.000000	12.000000
13	0.060000	0.060000	0.060000	0.060000	0.060000	0.060000
14	6.000000	6.115000	6.000000	6.115000	6.000000	6.115000
15*	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16	2.750000	2.750000	2.750000	2.750000	2.750000	2.750000
17	0.008789	0.008789	0.008789	0.008789	0.008789	0.008789
18	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
19	0.004883	0.004883	0.004883	0.004883	0.004883	0.004883
20	1	1	1	1	1	1
21	1	1	1	1	1	1

*Wilson Plot values not entered

$$h' = \frac{h_{uncorrected}}{1.035} \quad . \tag{5}$$

An adjustment for axial heat loss yields:

$$h'' = \frac{h'}{1 + \frac{2}{L}\sqrt{\frac{C * T}{h'}}} \tag{6}$$

where L is the length of the copper block in inches, C is thermal conductivity of the tube, and T is the wall thickness of the tube.

To allow for comparison between values of h calculated at different times, h was referenced to a nominal water temperature and flow velocity. The nominal water temperature and flow velocity were chosen to be 70° F and 6 feet per second. The heat transfer coefficient was adjusted with the equations:

$$h''' = h'' * \frac{1 + 0.0105*70}{1 + 0.0105*T} \tag{7}$$

where T was average water temperature in degrees Farenheit measured during the current test, and

$$\frac{1}{h} = \frac{1}{h'''} - \text{SLOPE} * (F^{-0.8} - 6^{-0.8}) \tag{8}$$

where SLOPE was the slope of the Wilson Plot line and F was the average water flow velocity measured during the test.

The fouling resistance was calculated by observing the difference in the rate of heat transfer from that of a clean tube

$$R_f = \frac{1}{h} - \frac{1}{h_{initial}}$$

where $h_{initial}$ was the initial heat transfer coefficient as determined from the Wilson Plot.

Tube data analyses were performed by the software subroutines HTCOEF, CCN, and LINFIT; listings of these programs are in Appendix A. Figure 4 shows a typical analysis printout; Table 3 contains an explanation of the analysis parameters. These parameters are also stored on a DEC RK01 floppy disk for future retrieval. Software was developed to print out tube data in a more easily read format, and to compute and plot the daily average and standard deviation of each parameter. An example printout is shown in Table 4; a plot of mean daily fouling resistance values is shown in Figure 5.

(Text Continued on Page 18)

TABLE 3

ANALYSIS PARAMETERS
(Sheet 1 of 2)

Parameter Number	Parameter Name	Explanation
1	ITUBE	tube number
2	IDATE	date
3	ITIME	time
4	VZERO*	minimum voltage to which thermopile dropped at the end of the cooling curve
5	DEV	standard deviation of VZERO
6	IFIT,I1,I2	fit number, beginning and end point number in cooling curve used for regression
7	VSTART*	maximum thermopile voltage at beginning of cooling curve
8	DEV	standard deviation of VSTART
9	TAU	time constant (seconds) of cooling curve
10	DEV	standard deviation of TAU
11	A	intercept of line in logarithmic cooling curve plot
12	DEV	standard deviation of A
13	B	slope of line in logarithmic cooling curve plot
14	DEV	standard deviation of B
15	R	correlation coefficient of logarithmic cooling curve plot
16	RMS	root mean square error of cooling curve plot
17-27		same as 6-16 except for second fit to cooling curve data
28	T	mean water temperature (degrees Celsius) during cooling cycle

*Values listed in A to D converter units can be converted to voltages by the relation:

$$\text{volts} = \frac{10 * AD}{4096}$$

TABLE 3
(Sheet 2 of 2)

Parameter Number	Parameter Name	Explanation
29	DEV	standard deviation of T
30	F	mean flow velocity in feet per second during cooling cycle
31	DEV	standard deviation of F
32	HUNCOR	uncorrected heat transfer coefficient (h)
33	HCOREW	h corrected for air and axial heat losses
34	TCOR	temperature correction to apply to h
35	HCREWT	temperature corrected 1/h
36	VCOR	velocity correction to apply to 1/h
37	HNOM	corrected, final h
38	FR	fouling resistance (ft^2-hr-^oF BTU^{-1})
39	IREC	record number for data storage

```
TUBE      4
DATE       601
TIME      11:14
VZERO     288.95     DEV   2.55
FIT   1 FROM DATA POINT        5 TO DATA POINT    122
VSTART    2237.     DEV    2.8
TAU        56.923    DEV   0.109
A          7.7131    DEV 0.0006
B         -0.01697    DEV 0.00002
R         -0.99261     RMS 19.18796
FIT   2 FROM DATA POINT        6 TO DATA POINT     10
VSTART    2299.     DEV    4.8
TAU        54.646    DEV   0.225
A          7.7404    DEV 0.0010
B         -0.01830    DEV 0.00004
R         -1.00001     RMS  1.11374
T          26.271    DEV 0.010
F          5.347    DEV 0.086
HUNCOR  1006.
HCOREW   954.
TCOR     0.928
HCREWT   885.
VCOR     0.5232E-01
HNOM     926.
FR        0.71E-04

ARCHIVED ON DATA DISK AS RECORD NUMBER    659
```

FIGURE 4. TYPICAL ANALYSIS PARAMETERS PRINTOUT

TABLE 4

TUBE DATA LISTOUT

FIRST AVAILABLE FREE RECORD 2056
TUBE NUMBER 2

REC#	DATE	TIME CST	VZERO A/D	TEMP C	FLOW FPS	FLOWSD SEC	TAU	HNOM	R	RMS	RFOUL E-4
854	622	0: 0	215.	26.91	5.627	0.031	55.42	907.	-1.00000	3.76	0.73
858	622	0:30	207.	27.13	5.615	0.025	55.76	894.	-0.99994	4.63	0.88
862	622	1: 0	203.	26.98	5.607	0.003	55.82	894.	-0.99994	4.94	0.89
866	622	1:30	206.	27.21	5.576	0.023	55.65	901.	-0.99985	4.59	0.80
870	622	2: 0	211.	27.12	5.592	0.003	55.78	896.	-0.99998	4.23	0.86
874	622	2:30	218.	27.22	5.678	0.030	55.48	896.	-0.99995	3.79	0.65
878	622	3: 0	226.	27.22	5.661	0.000	55.36	900.	-1.00000	3.61	0.81
883	622	3:30	224.	27.06	5.648	0.004	55.30	907.	-0.99993	3.18	0.72
888	622	4: 0	207.	27.08	5.603	0.023	55.46	906.	-0.99987	3.51	0.73
892	622	4:30	201.	27.02	5.605	0.012	55.92	891.	-1.00001	3.86	0.92
896	622	5: 0	227.	27.03	5.588	0.009	55.17	919.	-0.99993	2.62	0.59
901	622	5:30	232.	27.05	5.627	0.009	55.98	886.	-0.99990	6.10	0.98
906	622	6: 0	210.	26.90	5.656	0.038	55.19	912.	-0.99997	4.20	0.67
911	622	7:10	120.	27.04	5.774	0.018	54.96	906.	-0.99983	6.96	0.73
919	622	7:40	95.	27.11	5.790	0.015	54.55	918.	-0.99982	7.01	0.59
927	622	8:10	98.	27.17	5.789	0.008	54.29	927.	-0.99986	6.47	0.48
935	622	8:40	139.	27.16	5.837	0.026	53.72	943.	-0.99994	5.49	0.30
943	622	9:10	175.	27.23	5.807	0.017	54.26	926.	-0.99978	6.60	0.50
951	622	9:40	182.	27.22	5.762	0.003	54.54	921.	-0.99988	6.84	0.56
959	622	10:10	184.	26.95	5.747	0.004	54.94	911.	-0.99987	8.20	0.68
967	622	10:40	184.	26.94	5.796	0.016	54.73	913.	-0.99984	7.07	0.65
975	622	11:10	187.	26.95	5.750	0.004	54.67	920.	-0.99983	7.17	0.57
983	622	11:40	189.	27.15	5.767	0.003	54.74	914.	-0.99984	6.94	0.64
991	622	12:10	187.	27.24	5.796	0.022	54.52	918.	-0.99988	7.59	0.59
999	622	12:40	185.	27.45	5.808	0.019	54.65	910.	-0.99986	6.71	0.69
1007	622	13:10	186.	27.45	5.745	0.007	54.48	922.	-0.99992	7.32	0.54
1015	622	13:40	192.	27.43	5.809	0.021	54.53	914.	-0.99989	6.97	0.64
1023	622	14:10	192.	27.58	5.751	0.003	54.56	918.	-0.99981	7.28	0.59
1031	622	14:40	193.	27.74	5.800	0.005	54.69	906.	-0.99982	7.22	0.73
1039	622	15:10	194.	27.97	5.768	0.025	54.63	910.	-0.99983	6.85	0.69
1047	622	15:40	197.	28.07	5.752	0.010	54.44	917.	-0.99984	6.94	0.60
1055	622	16:10	200.	28.20	5.757	0.021	54.43	916.	-0.99980	6.63	0.62
1063	622	16:40	203.	28.39	5.759	0.006	54.42	914.	-0.99983	6.16	0.64
1071	622	17:10	210.	28.65	5.729	0.037	54.48	912.	-0.99979	5.96	0.66
1079	622	17:40	218.	29.03	5.832	0.018	54.36	903.	-1.00003	5.41	0.77
1087	622	18:10	224.	29.25	5.794	0.021	54.28	908.	-0.99981	6.06	0.72
1095	622	18:40	223.	29.30	5.798	0.010	54.25	908.	-0.99992	5.05	0.72
1103	622	19:10	224.	29.40	5.809	0.016	54.42	900.	-0.99983	3.93	0.81
1111	622	19:40	222.	28.61	5.856	0.041	54.47	901.	-0.99990	5.14	0.80
1119	622	20:10	224.	28.01	5.862	0.008	54.41	908.	-0.99981	6.70	0.72
1127	622	20:40	228.	27.94	5.839	0.022	54.50	908.	-0.99986	6.49	0.72
1135	622	21:10	222.	27.92	5.866	0.007	54.60	902.	-0.99988	5.82	0.79
1143	622	21:40	217.	28.14	5.790	0.006	54.39	914.	-0.99988	5.43	0.63
1151	622	22:10	221.	28.29	5.845	0.009	54.41	907.	-0.99987	5.01	0.73
1159	622	22:40	224.	28.22	5.837	0.035	54.56	903.	-0.99992	5.95	0.77
1167	622	23:11	224.	28.18	5.793	0.000	54.51	909.	-0.99982	6.00	0.69
1175	622	23:41	225.	28.29	5.810	0.015	54.55	905.	-0.99998	4.68	0.74
AVG	622	47	200.	27.65	5.747	0.015	54.79	909.	-0.99988	5.73	0.70
STD	622	47	31.	0.71	0.085	0.011	0.53	10.	0.00029	1.37	0.124

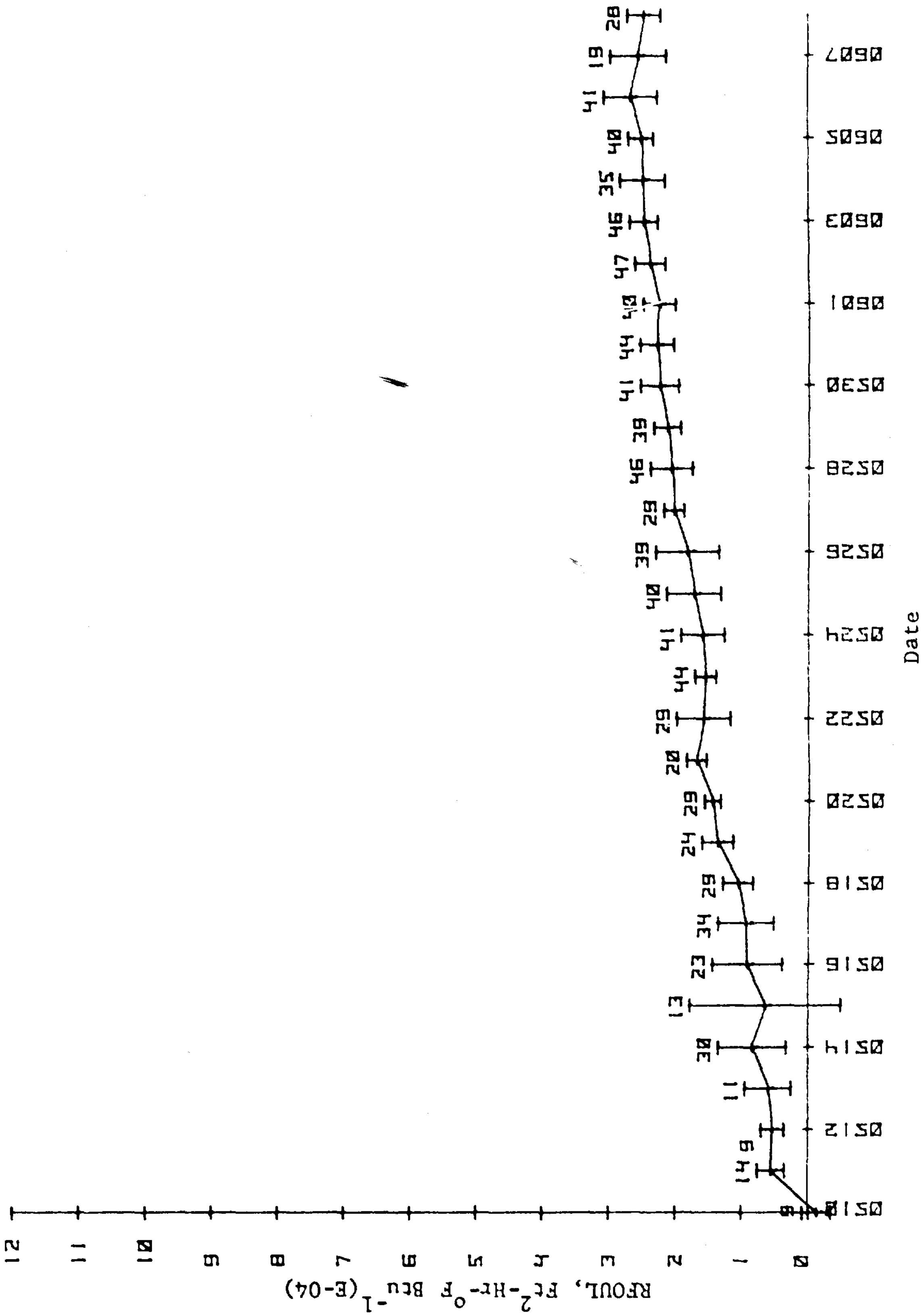

FIGURE 5. MEAN DAILY FOULING RESISTANCE VALUES

SYSTEM RELIABILITY

The OTEC computer system at Pnaama City demonstrated good reliability throughout testing, with brief and infrequent computer "down" times. Computer hardware performed well despite round-the-clock operation and an operating environment (a trailer on the pier) with poor temperature and humidity control. Only one major breakdown was experienced last year due to a lightning strike blowing out one of the computer power supplies.

Computer software was continuously modified to allow for system expansion and enhancement of control techniques, and allowing for more accurate analysis of data. Additional software routines, written in BASIC language for use on a Hewlett-Packard 9830A programmable calculator, have provided for cross-checking of results as well as allowing for graphical representation of data.

Fouling resistance was determined for each tube at the end of the cool down cycle; a maximum of 48 analyses were done for each tube in a 24 hour period. The main loss of data was due to a tube being dropped from a test because of flow or heater problems; in such a case, no analyses were done for that tube. All analysis data were rechecked and not used if other problems, such as high flow deviation or high RMS errors, were detected. Errors on the analysis parameters from one run are listed in Table 5. These errors varied between tubes but were consistent for each tube. They appeared to be small enough to allow for adequate day-to-day comparison of RFOUL values.

TABLE 5

PARAMETER ERRORS

	Tube 1	Tube 2	Tube 3	Tube 4	Tube 5	Tube 6	Tube 7	Tube 8
Date	0625	0625	0625	0625	0625	0625	0625	0625
Time	11:38	11:38	11:38	11:38	11:38	11:38	11:38	11:38
VZERO	333.50	196.55	367.15	202.20	132.90	229.60	235.80	135.30
σ	2.33	3.58	2.28	2.55	1.33	6.06	3.69	5.24
VSTART	2425	2183	3018	2666	2771	2483	2694	2194
σ	2.9	6.5	3.1	4.2	1.7	9.9	4.6	9.4
Tau	46.565	54.122	42.906	69.382	49.661	63.819	43.046	52.424
σ	0.103	0.301	0.080	0.228	0.065	0.482	0.122	0.391
A	7.7937	7.6884	8.0124	7.8884	7.9268	7.9172	7.8989	7.6935
σ	0.0006	0.0015	0.0005	0.0008	0.0003	0.0020	0.0009	0.0021
B	-0.02148	-0.01848	-0.02331	-0.01441	-0.02014	-0.01567	-0.02323	-0.1908
σ	0.00002	0.00005	0.00002	0.00002	0.00001	0.00006	0.00003	0.00007
R	-0.99978	-0.99991	-0.99991	-1.00000	-1.00000	-9.99996	-0.99979	-0.99967
RMS	9.764	5.952	5.377	1.227	1.319	4.772	11.750	10.291
T	28.010	27.974	27.874	28.152	28.158	28.105	28.092	28.199
σ	0.007	0.007	0.006	0.004	0.003	0.003	0.005	0.007
F	5.501	5.976	5.989	5.430	5.653	4.830	5.714	6.322
σ	0.001	0.027	0.006	0,006	0.028	0.006	0.019	0.086
FR	0.99e-4	0.72e-4	4.73e-4	6.90e-4	4.29e-4	2.39e-4	2.84e-4	1.90e-4

(Reverse Page 21 Blank)

APPENDIX A

ANALYSIS PROGRAM LISTOUTS

```
TT:=DX1:HTCOEF.FOR
C       FILE HTCOEF.FOR 3/22/79-2
C       ASF FOR OTEC
C
        SUBROUTINE HTCOEF(ITUBE)
        BYTE ITUBE
        COMMON /ADATA/IVTC(300),IVTH(300),IVFM(300)
        COMMON /FLOPPY/INTS(4),REALS(24)
        DIMENSION Y(300),WT(300)
C
C       ITUBE=THE TUBE NUMBER
C
        COMMON /PRE/IDTEST,IHR,IMIN,NPRELM,IEND,NZERO
        COMMON /MISC/ISAMPI
        COMMON /DATE/IDAY
C
C       IDAY,IHR,IMIN=DAY, HOUR, MINUTE OF START OF DATA
C       NPRELM=#POINTS BEFORE HEATER OFF
C       IEND=TOTAL N# DATA POINTS
C       ISAMP=SAMPLING INTERVAL IN SECONDS
C
        COMMON /HPARAM/ACCN,BCCN,CCCN,DCCN,RAD1,RAD2,RAD3,
        1 AKCYL,AKTUBE,HAIR,HINTR,ALNGTH,TTHWLL,VNOM,HRSLPE,
        2 THINT,THSLP,FMINT,FMSLP,IWNST,IWN
C
C       ACCN,BCCN,CCCN,DCCN CURVE FIT FOR H=F(TAU)
C       RAD1=1/2 ID OF TUBE (IN)
C       RAD2=1/2 OD OF TUBE (IN)
C       RAD3=1/2 OD OF TUBE (IN)
C       AKCYL=THERMAL COND. OF HEATER CYLINDERS (BTU/HR FT F).
C       AKTUBE=THERMAL COND. OF TUBE (BTU/HR FT F).
C       HAIR=CONVECTIVE COEFFICIENT FOR HEAT LOSS TO AIR
C       HINTR=INTERC. ON ORDINATE AXIS IN 1/H VRS. 1/V**.8 PLOT
C       ALNGTH=LENGTH OF HEATER CYLINDER SET (IN)
C       TTHWLL=WALL THICKNESS OF THIN-WALLED SECTION OF TUBE (IN)
C       VNOM=NOMINAL FLOW VELOCITY IN TUBE IN FT/SEC
C       HRSLPE=SLOPE OF 1/H TO 1/(V**.8) CURVE (WILSON PLOT)
C       THINT=INTERCEPT IN CENT. DEG. OF THE THERMISTER CURVE
C       (TWATER=THINT+THSLP*IVTH)
C       THSLP=SLOPE OF THERMISTER CURVE
C       FMINT=INTERCEPT IN GAL/MIN OF THE THERMISTER CURVE
C       (FLOW=FMINT+FMSLP*IVFM)
C       FMSLP=SLOPE OF FLOW METER CURVE
C       IWNST=SAMPLE AT WHICH WINDOW TO START AFTER NPRELM
C       IWN=NUMBER OF TIME CONSTS. FOR FINAL WINDOW
C       RTHENT FUDGE FACTOR TO ALLOW FOR AIR HEAT LOSS
C
C       TUBEID=ID OF HEAT EXCHANGER TUBE (IN)
C
C
        COMMON /ICOOL/IPRTC
C
        ISAMP=ISAMPI/60
C
C       IF TUBE IS TITANIUM - LOOK AT EVERY OTHER SAMPLE
C               SO ISAMP SHOULD BE DOUBLED
C
        IF(AKTUBE.LT.50.)ISAMP=ISAMP*2
        IHR=MOD(IHR,24)
        INTS(1)=ITUBE
        INTS(2)=IDAY
        INTS(3)=IHR
        INTS(4)=IMIN
C
        WRITE(7,1300)ITUBE,IDAY,IHR,IMIN
1300    FORMAT(//// TUBE    ',I2// DATE    ',I4// TIME    ',I2,':',I2)
```

```
C
C       GET PARAMETERS FOR THE TUBE
C
        TUBEID=RAD1*2.
C
C       GET THERMOCOUPLE ZERO POINT AND STD.DEV.
C
        VTCZRO=0.
        I1=IEND-NZERO+1
        DO 100 I=I1,IEND
100     VTCZRO=VTCZRO+IVTC(I)
        VTCZRO=VTCZRO/NZERO
        STDZRO=0.
        DO 110 I=I1,IEND
110     STDZRO=STDZRO+(IVTC(I)-VTCZRO)**2
        STDZRO=SQRT(STDZRO/(NZERO-1))
        REALS(1)=VTCZRO
        REALS(2)=STDZRO
        WRITE(7,1000)VTCZRO,STDZRO
        IF(STDZRO.NE.0.)GO TO 606
        WRITE(7,6077)
6077    FORMAT(///' ANALYSIS ERROR'//)
        RETURN
606     CONTINUE
1000    FORMAT(' VZERO    ',F6.2,'    DEV ',F5.2)
C
C       SHIFT THERMOCOUPLE DATA TO THE ZERO POINT
C
        NP1=NPRELM+1
        DO 200 I=NP1,IEND
 200    Y(I)=IVTC(I)-VTCZRO
C
C    PRINT RAW DATA (THERMOPILE, THERMISTOR, FLOW) IF IPRTC=1
C    PRINTED VALUES ARE IN A/D CONVERTER UNITS
C
        IF (IPRTC.NE.1) GO TO 978
        DO 201 I=1,IEND
 201    WRITE (7,979) IVTC(I),IVTH(I),IVFM(I)
 979    FORMAT (4X,3I12)
 978    CONTINUE
C
C
C       SET UP DATA ARRAY FOR FIT
C
        DO 300 I=NP1,IEND
        ARG1=Y(I)
        ARG=ABS(ARG1)
        IF (ARG.LT..001)ARG=.001
        Y(I)=ALOG(ARG)
        IF (ARG1.LE.0.)ARG1=.001
300     WT(I)=(ARG1/STDZRO)**2
C
C       DO FITS OF DATA
C
        DO 999 IFIT=1,2
        IF (IFIT.EQ.2)GOTO 350
C
C       FIRST FIT FROM NPRELM TO IEND
C
        I1=NP1
        I2=IEND
        GOTO 400
C
C       SECOND FIT FROM IWNST TO IWN TIME CONSTANTS
C
350     I1=IWNST+NP1
```

```
      I2=I1+IWN*TAU/ISAMP
C
400   NPTS=I2-I1+1
      WRITE(7,2731)IFIT,I1,I2
2731  FORMAT(' FIT ',I2,' FROM DATA POINT ',I5,
     1 ' TO DATA POINT ',I5)
      CALL LINFIT(Y(I1),WT(I1),NPTS,A,SIGMAA,B,SIGMAB,
     1 R,RMS,CHITOT,STD,I1,ISAMP,NPRELM,IDN)
C
C     WE HAD VTC(T)=(VO)*EXP(-T/TAU)  WE HOPED
C     WE MADE Y(T)=LOG(VO)-T/TAU
C            OR       A + B*T
C
C
C
      VO=EXP(A)
      VOHIGH=EXP(A+SIGMAA)
      VOLOW=EXP(A-SIGMAA)
      TAU=-1./B
      TAUHI=-1./(B+SIGMAB)
      TAULOW=-1./(B-SIGMAB)
      INTAU=NPTS*ISAMP
      DV=VOHIGH-VOLOW
      DTAU=TAUHI-TAULOW
      REALS(3)=VO
      REALS(4)=DV
      REALS(5)=TAU
      REALS(6)=DTAU
      REALS(7)=A
      REALS(8)=SIGMAA
      REALS(9)=B
      REALS(10)=SIGMAB
      REALS(11)=R
      WRITE(7,1100)VO,DV,TAU,DTAU
1100  FORMAT(' VSTART  ',F5.0,'   DEV ',F5.1/
     1      ' TAU    ',F7.3,'   DEV ',F6.3)
      WRITE(7,1150)A,SIGMAA,B,SIGMAB,R,RMS
1150  FORMAT(' A       ',F7.4,'   DEV ',F6.4/
     1      ' B       ',F8.5,'   DEV ',F7.5/
     2      ' R       ',F8.5,'    RMS ',F8.5)
C
C     GET WATER TEMP AND FLOW VEL. OVER ANALYSIS
C
      AVETW=0.
      AVEFV=0.
      ALINFM=.4085/TUBEID**2
      DO 425 I=I1,I2
      AVETW=AVETW+THINT+THSLP*IVTH(I)
      AVEFV=AVEFV+ALINFM*(FMINT+FMSLP*IVFM(I))
425   CONTINUE
      AVETW=AVETW/NPTS
      AVEFV=AVEFV/NPTS
      STDWT=0.
      STDFV=0.
      DO 450 I=I1,I2
      STDWT=STDWT+(THINT+THSLP*IVTH(I)-AVETW)**2
      V=ALINFM*(FMINT+FMSLP*IVFM(I))
450   STDFV=STDFV+(V-AVEFV)**2
      STDWT=SQRT(STDWT/(NPTS-1))
      STDFV=SQRT(STDFV/(NPTS-1))
      REALS(12)=AVETW
      REALS(13)=STDWT
      REALS(14)=AVEFV
      REALS(15)=STDFV
      IF(IFIT.EQ.2)WRITE(7,1200)AVETW,STDWT,AVEFV,STDFV
1200  FORMAT(' T       ',F7.3,'   DEV ',F5.3/
```

```
      1       ' F         ',F6.3,     DEV ',F5.3)
C
C     NOW GET H
C
      CALL CCN(TAU,AVETW,AVEFV,IFIT,RMS)
      IF (IFIT.EQ.2)WRITE(7,1500)
1500  FORMAT(/)
C
999   CONTINUE
C
      IF(.NOT.IOK)RETURN
C
C     WRITE OUTPUT TO FLOPPY DRIVE IF POSSIBLE
C
      CALL ASSIGN(8,'DX1:OUTPUT.DAT',14,'OLD')
      DEFINE FILE 8(2300,52,U,IV)
      READ(8'1)IRECNO
      IF(IRECNO.GT.2300
      1    .OR.IRECNO.LT.0)
      2       GO TO 9999
      WRITE(8'IRECNO)INTS,REALS
      WRITE(7,3077)IRECNO
3077  FORMAT(' ARCHIVED ON DATA DISK AS RECORD NUMBER ',I5,//)
      IRECNO=IRECNO+1
      WRITE(8'1)IRECNO
      CALL CLOSE(8)
      RETURN
9999  WRITE(7,2349)IRECNO
2349  FORMAT(' ILLEGAL RECORD NUMBER FOR FLOPPY OUTPUT ',I5/
      1       1X,30(1H*)//
      2       ' PREVIOUS RECORD NOT ARCHIVED '
      3       //' PLEASE ARRANGE FOR NEW DATA DISK'
      4       //1X,30(1H*)///)
      CALL CLOSE(8)
      RETURN
      RETURN
      END
*     END
```

Best Available Copy

```
VT:NXX.DX1:CON.FOR
C       FILE CON.FOR 3/21/79-2
C
C       ASF FOR OTEC
C       MODIFIED BY GLS 7/13/79
C
        SUBROUTINE CON(TAU,TWATER,FLOVEL,IFIT,RMS)
C
        COMMON /HPARAM/A,B,C,D,RAD1,RAD2,RAD3,AKCYL,AKTUBE,
        1 HAIR,HINTR,ALNGTH,TTHWLL,VNOM,HRSLPE,THINT,THSLP,
        2 FMINT,FMSLF,IWNST,IWN
        COMMON /FLOFFY/INTS(4),REALS(24)
C
C       RAIR=0 DUE TO PREVIOUS CORRECTION IN HTAUR
C
        IF (TAU.LT..0001)RETURN
        FNTAU=ALOG(TAU)
        FNH=A+FNTAU*(B+FNTAU*(C+D*FNTAU))
        HUNCOR=EXP(FNH)
C
        RTHENT=1.035
        HVDTE=HUNCOR/RTHENT
C
        WLLCON=(2./ALNGTH*12.)*SQRT(AKTUBE*TTHWLL/12.)
        RWALLS=WLLCON/SQRT(HVDTE)
        HCOREW=HVDTE/(1.0+RWALLS)
C
        ANORM=(1.+.0105*70.)/(1.+.0105*(1.8*TWATER+32.))
        HCREWT=ANORM*HCOREW
        HCEWTR=1.0/HCREWT
C
        REALS(16)=HUNCOR
        REALS(17)=HCOREW
        REALS(18)=ANORM
        REALS(19)=HCREWT
C
        IF(IFIT.EQ.2)WRITE(7,100)HUNCOR,HCOREW
  100   FORMAT(' HUNCOR ',F5.0/' HCOREW ',F5.0)
        IF(IFIT.EQ.2)WRITE(7,200)ANORM,HCREWT
  200   FORMAT(' TCOR    ',F6.3/' HCREWT ',F5.0)
C
        VBR=FLOVEL**(-.8)
        VNOMBR=VNOM**(-.8)
        VELCOR=HRSLPE*(VBR-VNOMBR)
        HRNOM=HCEWTR-VELCOR
        HNOM=1./HRNOM
        RFOUL=HRNOM-(HINTR+HRSLPE*VNOMBR)
C
        REALS(20)=VELCOR
        REALS(21)=HNOM
        REALS(22)=RFOUL
        REALS(23)=RMS
        REALS(24)=0.0
C
        RFOULP=RFOUL*1.E4
        IF(IFIT.EQ.2)WRITE(7,300)VELCOR,HNOM,RFOULP
  300   FORMAT(' VCOR    ',E11.4/' HNOM    ',F5.0/' FR      ',F6.2,'E-04')
        RETURN
        END
*
```

```
TT:=DX1:LINFIT.FOR
C        FILE LINFIT.FOR 6/15/78-1
C
C        ASF FOR OTEC
C
         SUBROUTINE LINFIT(Y,WT,NPTS,A,SIGMAA,B,SIGMAB,R,
         1 RMS,CHITOT,STD,I1,ISAMP,NPRELM,IOK)
C
         DIMENSION Y(1),WT(1)
C
         IOK=.TRUE.
         SUM=0.
         SUMX=0.
         SUMY=0.
         SUMX2=0.
         SUMXY=0.
         SUMY2=0.
         ITIME=(I1-2-NPRELM)*ISAMP
C
         DO 50 I=1,NPTS
         XI=I*ISAMP+ITIME
         YI=Y(I)
         WEIGHT=WT(I)
C
         SUM=SUM+WEIGHT
         SUMX=SUMX+WEIGHT*XI
10000    FORMAT(1X,3E15.6)
         SUMY=SUMY+WEIGHT*YI
         SUMX2=SUMX2+WEIGHT*XI*XI
         SUMXY=SUMXY+WEIGHT*XI*YI
         SUMY2=SUMY2+WEIGHT*YI*YI
50       CONTINUE
C
         DELTA=SUM*SUMX2-SUMX*SUMX
         A=(SUMX2*SUMY-SUMX*SUMXY)/DELTA
         B=(SUMXY*SUM-SUMX*SUMY)/DELTA
C
C    COMPUTE RMS ERROR ON COOLING CURVE FIT
         DELTAY=0.0
         DO 947 I=1,NPTS
         XI=I*ISAMP+ITIME
         YI=EXP(B*XI+A)
         YJ=EXP(Y(I))
 947     DELTAY=DELTAY+(YJ-YI)**2
         RMS=SQRT(DELTAY/FLOAT(NPTS))
C
         CHITOT=0.
         DO 55 I=1,NPTS
         XXX=A+B*(I*ISAMP+ITIME)
         CHITOT=CHITOT+WT(I)*(XXX-Y(I))**2
55       CONTINUE
C
         VAL1=SUMX2/DELTA
         VAL2=SUM/DELTA
999      IF(VAL1.GE.0.AND.VAL2.GE.0)GO TO 606
         WRITE(7,6077)
6077     FORMAT(//'ANALYSIS ERROR'//)
         IOK=.FALSE.
         RETURN
606      CONTINUE
         SIGMAA=SQRT(VAL1)
         SIGMAB=SQRT(VAL2)
         VAL1=DELTA*(SUM*SUMY2-SUMY*SUMY)
         IF(VAL1.GT.0.)GO TO 6061
```

```
      WRITE(7,6077)
      IOK=.FALSE.
      RETURN
6061  CONTINUE
      R=(SUM*SUMXY-SUMX*SUMY)/SQRT(VAL1)
      IF(SUM.EQ.0.)GO TO 999
      IF(NPTS-2.EQ.0)GO TO 999
      IF(CHITOT.LT.0..OR.SUM.LT.0.
     1   .OR.FLOAT(NPTS)/(FLOAT(NPTS)-2.).LT.0)GO TO 9995
      STD=SQRT((FLOAT(NPTS)/(FLOAT(NPTS)-2.))*(CHITOT/SUM))
      RETURN
9995  WRITE(7,9996)CHITOT,SUM,NPTS
9996  FORMAT(' CHITOT ',E14.6,' SUM ',E14.6,' NPTS ',I3)
      IOK=.FALSE.
      RETURN
      END
```

VARIABLES - HTCOEF, LINFIT, CCN Analysis Programs (others defined at beginning of HTCOEF routine)

1)	VTCZRO	average minimum value of voltage at tail of cooling curve (VZERO on analysis print out)
2)	STDZRO	standard deviation of VTCZRO, should be small
3)	NZERO	# points used for VTCZRO calculation
4)	NPRELM	# points at beginning of cooling curve to ignore
5)	NP1	first good cooling curve point (NPRELM +1)
6)	IEND	last cooling curve point
7)	I1,I2	first, last point of cooling curve to put through linear fit
8)	NPTS	# points put into linear fit
9)	VØ	beginning voltage (A/D units) for linear fit (VSTART on analysis printout)
10)	DV	standard deviation of VØ
11)	TAU	time constant of cooling curve
12)	DTAU	standard deviation of TAU
13)	A	intercept of logarithmic cooling curve fit
14)	SIGMAA	standard deviation of A
15)	B	slope of logarithmic cooling curve fit
16)	SIGMAB	standard deviation of B
17)	R	correlation coefficient of linear fit
18)	RMS	RMS error of linear fit
19)	AVETW,TWATER	average water temperature (T on analysis printout)
20)	AVEFV,FLOVEL	average flow velocity (F on analysis printout)
21)	IFIT	# of linear fit to cooling curve (is done twice)

22) ALINFM gal/min to ft/sec conversion

23) STDWT standard deviation of water temperature

24) STDFV standard deviation fo flow velocity

25) OUTPUT.DAT disk storage file for analysis parameters

26) IRECNO record # for storage on disk

27) SUM,SUMX,SUMY,SUMX2,SUMXY,SUMY2 summation indices

28) ITIME beginning sampling time minus one point

29) XI time for sample I

30) YI point #I for linear fit (normalized logarithm of sample)

31) WEIGHT weight to apply to YI

32) FNTAU log of TAU (base e)

33) FNH log of heat transfer coefficient, L (base e)

34) HUNCOR uncorrected L

35) RTHENT correction to L for air heat loss inside PVC housing (horizontal tubes)

36) WLLCON,RWALLS correction to L for axial heat loss along tube wall

37) HVDTE h, corrected for heat loss to air

38) HCOREW h, corrected for axial heat loss

39) ANORM temperature correction for h (TCOR on analysis printout)

40) HCREWT h, normalized to 70% temperature

41) HCEWTR 1/ HCREWT

42) V8R average flow velocity to -.8 power

43) VNOM nominal flow velocity (6 fps)

44) VNOM8R VNOM to -.8 power

45) VELCOR velocity correction for 1/h (VCOR on analysis printout)

46) HRNOM 1/h (corrected)

47) HNOM corrected h

48) RFOUL fouling coefficient (FR on analysis printout)

49) RFOULP RFOUL * 1.0E4

INITIAL DISTRIBUTION LIST

054	Chief of Naval Research	
	(Code 460T)	(Copy 1)
	(Code 463)	(Copy 2)
---	Argonne National Laboratories	
	9700 S. Cass Avenue, Argonne, Illinois 60439	
	(Mr. Glenn Popper)	(Copy 3)
	(Mr. George Danek, Consultant)	(Copy 4)
	(Mr. A. P. Gavin)	(Copy 5)
	(Mr. Joseph Draley)	(Copy 6)
---	Carnegie-Mellon University (Mr. Glenn N. Grannemann)	
	Physics Department,	
	Pittsburgh, Pa. 15213	(Copies 7,8)
---	David W. Taylor Naval Ship Research and Development Center	
	(Code 2731 - Mr. David Boswell)	(Copy 9)
	Annapolis, Maryland 21402	
---	Department of Energy, Division of Solar Technology	
	(Mr. Gene Kinelski)	(Copy 10)
	(Mr. Sigmund Gronich)	(Copy 11)
	600 E. Street, N.W.	
	Washington, D. C. 20545	
263	Naval Training Equipment Center, Attn: Tech. Library	(Copy 12)
---	Center for Energy & Environmental Research	
	(Mr. Juan A. Bonnett, Jr., Director)	(Copy 13)
	Caparra Heights Station, San Juan, Puerto Rico 00935	
---	University of Hawaii, Department of Ocean Engineering	
	(Mr. Charles L. Bretscheider, Chairman)	(Copy 14)
	2565 The Mall - Keller 219, Honolulu, Hawaii 96822	
---	TRW, Inc.	
	One Space Park, Redondo Beach, California 90278	
	(Linda Sinary Friedman, Asst. Project Manager)	(Copy 15)
	(M. J. Watson, OTEC-1 APM)	(Copy 16)
---	Hawaii Natural Energy Institute	
	(Mr. Lawrence Hallanger, Project Manager)	(Copy 17)
	206 Holmes Hall	
	2540 Dole St.,	
	Honolulu, Hawaii 96822	
---	Ocean Energy Systems, Lockheed Missiles & Space Co., Inc.,	
	P. O. Box 504, Sunnyvale, California 94086	
	(Mr. Thomas P. Higgins, manager)	(Copy 18)
---	Center for Energy and Environmental Research	
	(Dr. D. W. Sassler)	(Copy 19)
	Mayagiez. Puerto Rico 00708	
---	University of Hawaii, 74-55630 Kaiwi St.,	
	Kailua-Kona, Hawaii 96740	
	(Mr. Henry J. White)	(Copy 20)
075	Director, Defense Technical Information Center	(Copies 21-22)